



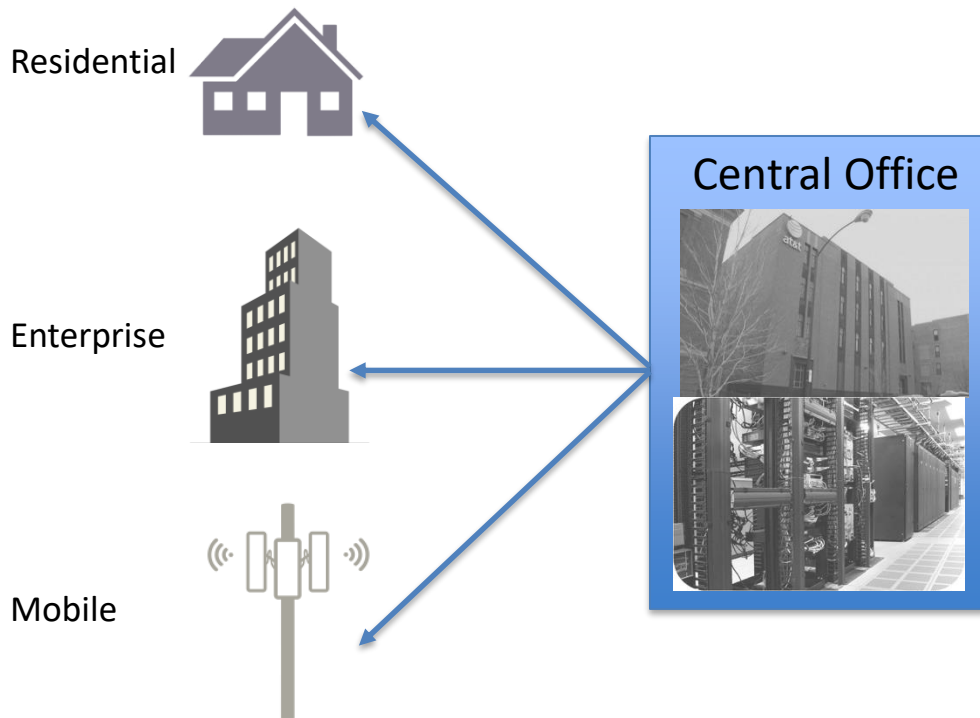
Mobile CORD (M-CORD)

Open Reference Solution for 5G

ONK 2017

Central Office

The Most Important Infrastructure for Service Providers



- CO is a service provider's "gateway" to its customers
- One central office (CO) may support
 - 10K+ residential subscribers
 - 10K+ mobile subscribers
 - 1K+ enterprise customers
- CO represents a great vantage point for a service provider
 - Enable new services to customers

¹Central Office can be small or large and has different names in different contexts.

CORD (Central Office Re-Invented as Data Center) High Level Architecture



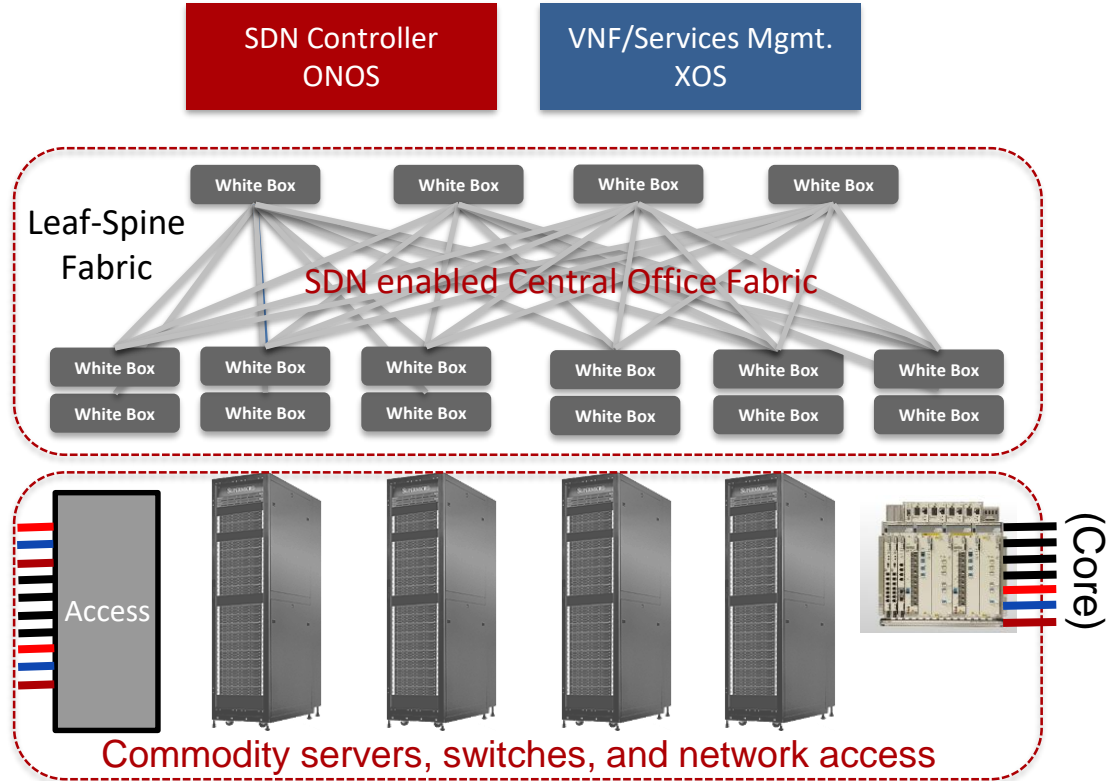
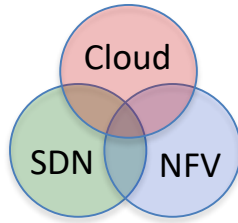
Large number of COs



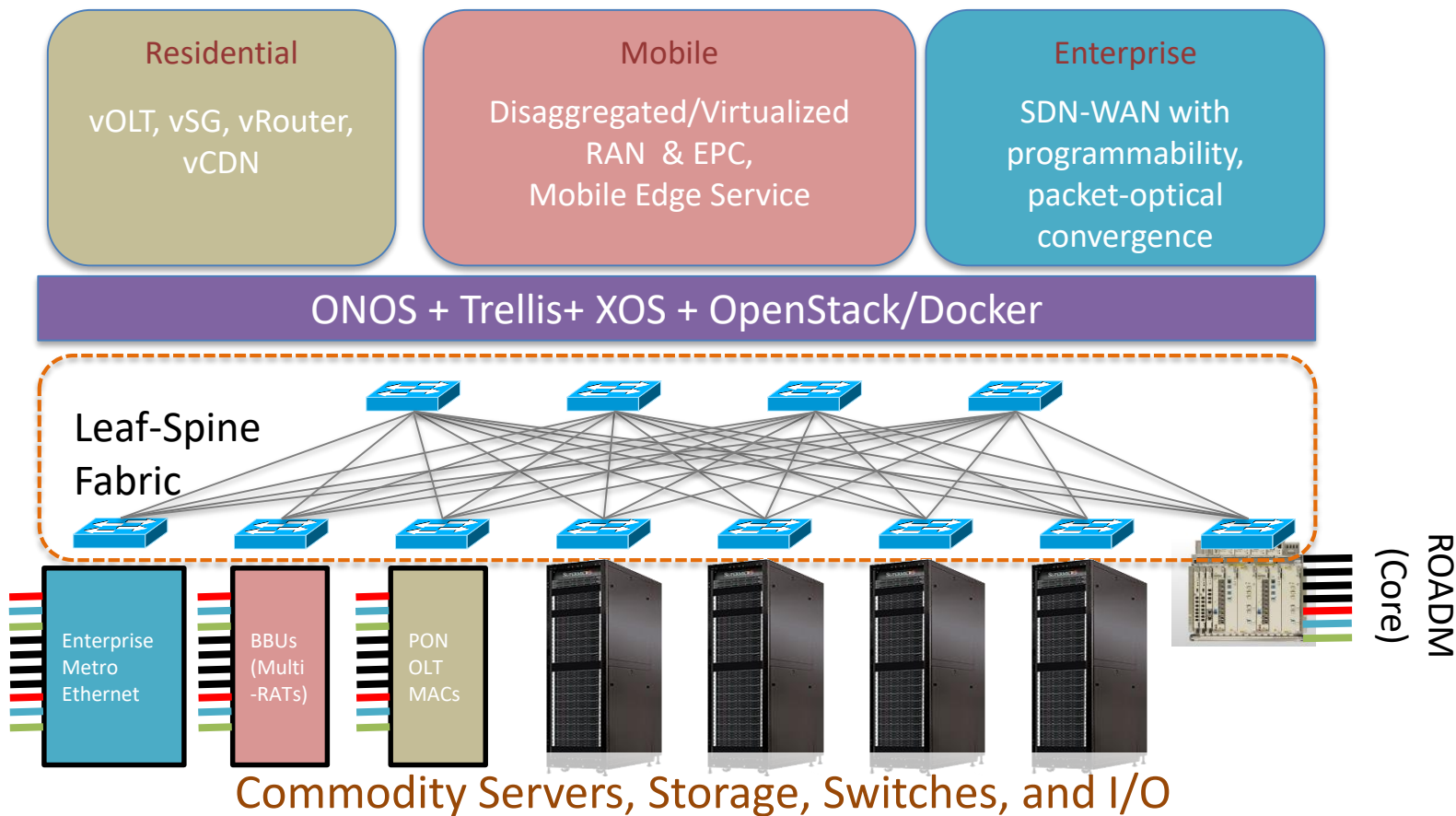
Evolved over 40-50 years



300+ Types of equipment
Huge source of CAPEX/OPEX

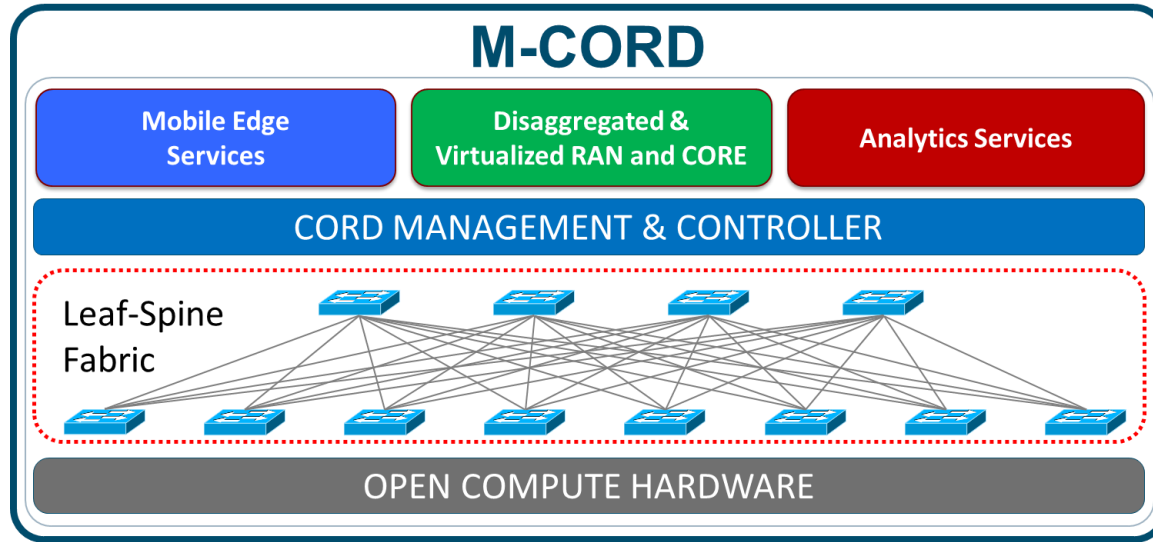


Domains of Use: Residential, Mobile, Enterprise



Mobile CORD (M-CORD) Solution

Accelerate 5G Journey



Open Source* Mobile Infrastructure

Open RAN and CORE for rapid
5G innovation

Open Source Control and Management

Ultimate flexibility through
end to end orchestration

Open Compute Platform

High density and scale,
carrier grade open platform

M-CORD architecture principles

Programmability

User plane / Control planes decoupling

SDN control plane is logically centralized

Mobile network functions are disaggregated

Scalability

Virtualized functions are composed as scalable serv

Cloud style Scale up & down

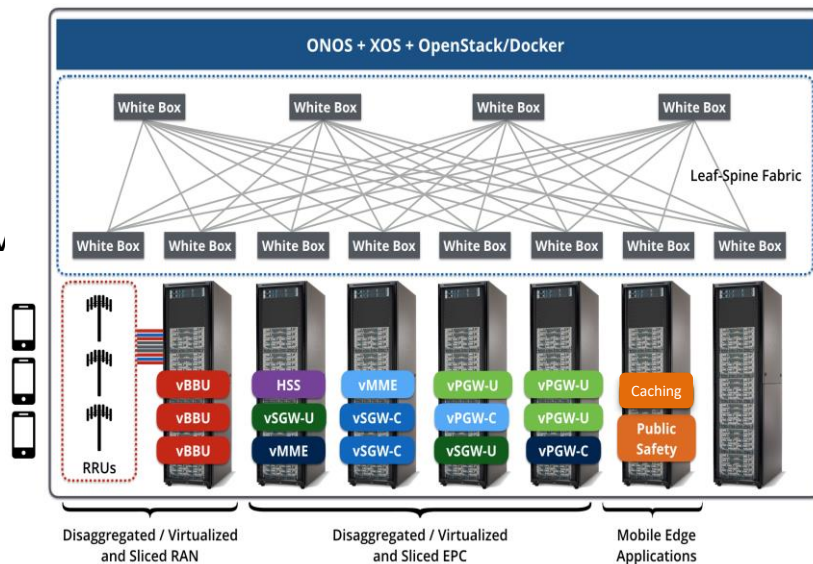
Can be used in different scenarios and locations

Orchestrability

XaaS (XOS composes service instances)

Observability & Close-loop analytics (A-CORD)

Dynamic End-to-End Network slicing



M-CORD mobile network re-architecting

RAN re-architecting

- RAN Split

- RAN Slicing

- Open source RAN (L2, L3 from Radisys)

CORE re-architecting

- EPC CP/UP separation

- MME disaggregation

- CORE Slicing

- Open source EPC (SDN-ized SGW/PGW from Radisys)

- Open source Connectionless GW (from Intel)

M-CORD Turnkey POD

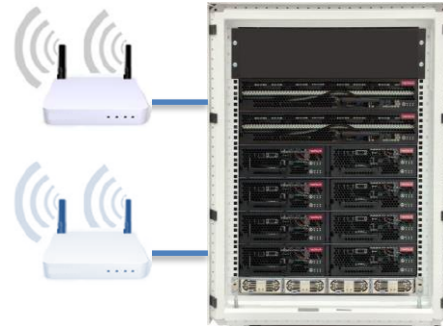


M-CORD Mini POD



- OCP compliant
- 6U compact
- Low cost
- Targeted for lab trial (PoC)

M-CORD POD



- Carrier grade OCP compliant
- 16U
- Targeted for field trial
- Modular and scalable

Mobile CORD (M-CORD) @ MWC 2017



ON.LAB

CORD
Central Office Re-architected as a Datacenter

Mobile CORD: Open Reference Solution for 5G

Contributing Members



Google



radisys



verizon

Collaborators

ARGELA



COBHAM



Quortus

Sprint

VIAT

xpose

M-CORD Innovations at MWC 2017

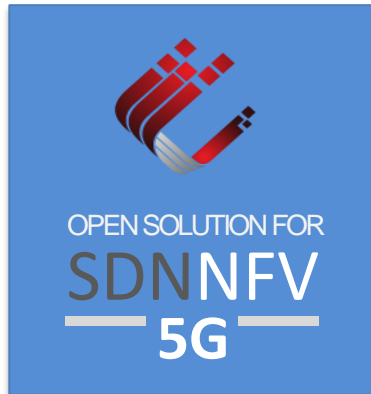


INFRASTRUCTUR

I Optimized CORE for IoT

II Scalable & Connectionless CORE

III End to End Network slicing



SERVICES

IV Premium Safety Service

V Analytics as a Service

Virtualized, Disaggregated, and Programmable



M-CORD Innovations: Optimized CORE for IoT



4G^{LTE}

Static IoT on current LTE leads to excessive signal overhead

M-CORD

Mobile Edge Services

Disaggregated & Virtualized RAN and CORE

Analytics Services

CORD MANAGEMENT & CONTROLLER

Leaf-Spine Fabric



OPEN COMPUTE HARDWARE

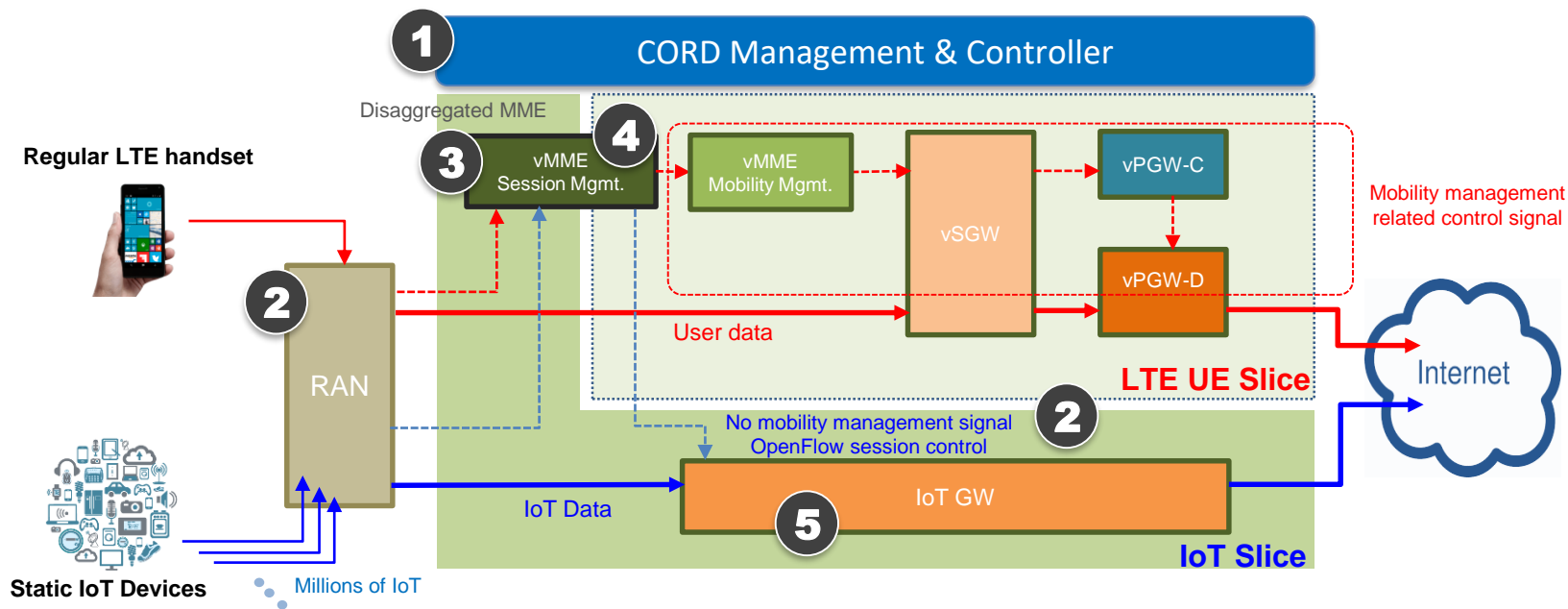


- MME disaggregation
- IoT GW
- Core slicing

Optimized Mobile CORE for Static IoT



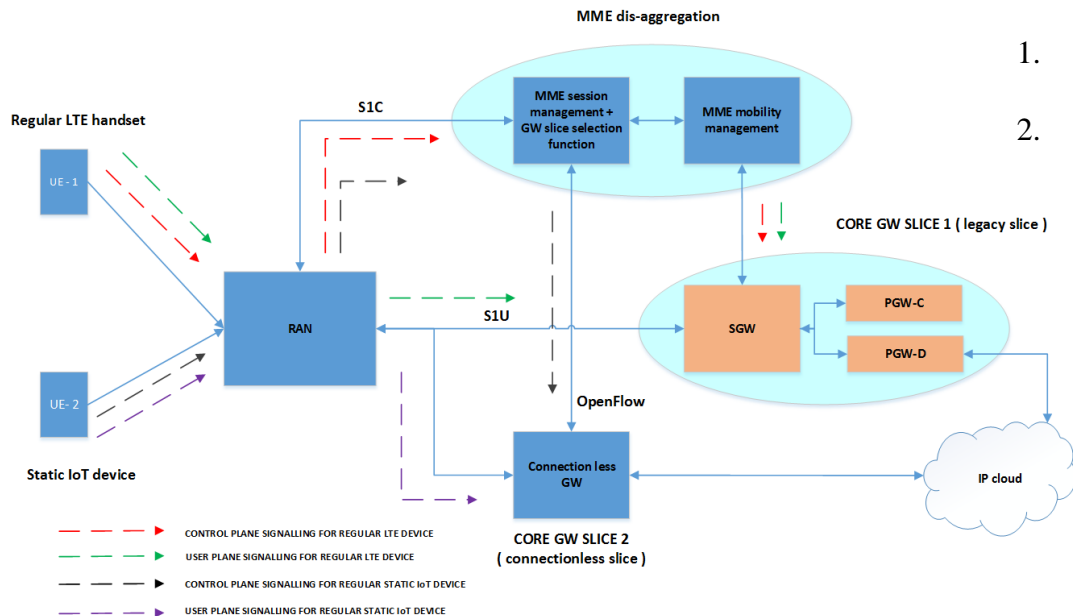
M-CORD Innovations: Optimized CORE for IoT



- 1 CORD Open Software Platform
- 2 Open source RAN and EPC

- 3 Disaggregation of MME functions
- 4 Slice selection service/function
- 5 IoT GW (data plane)

Optimized CORE for IoT

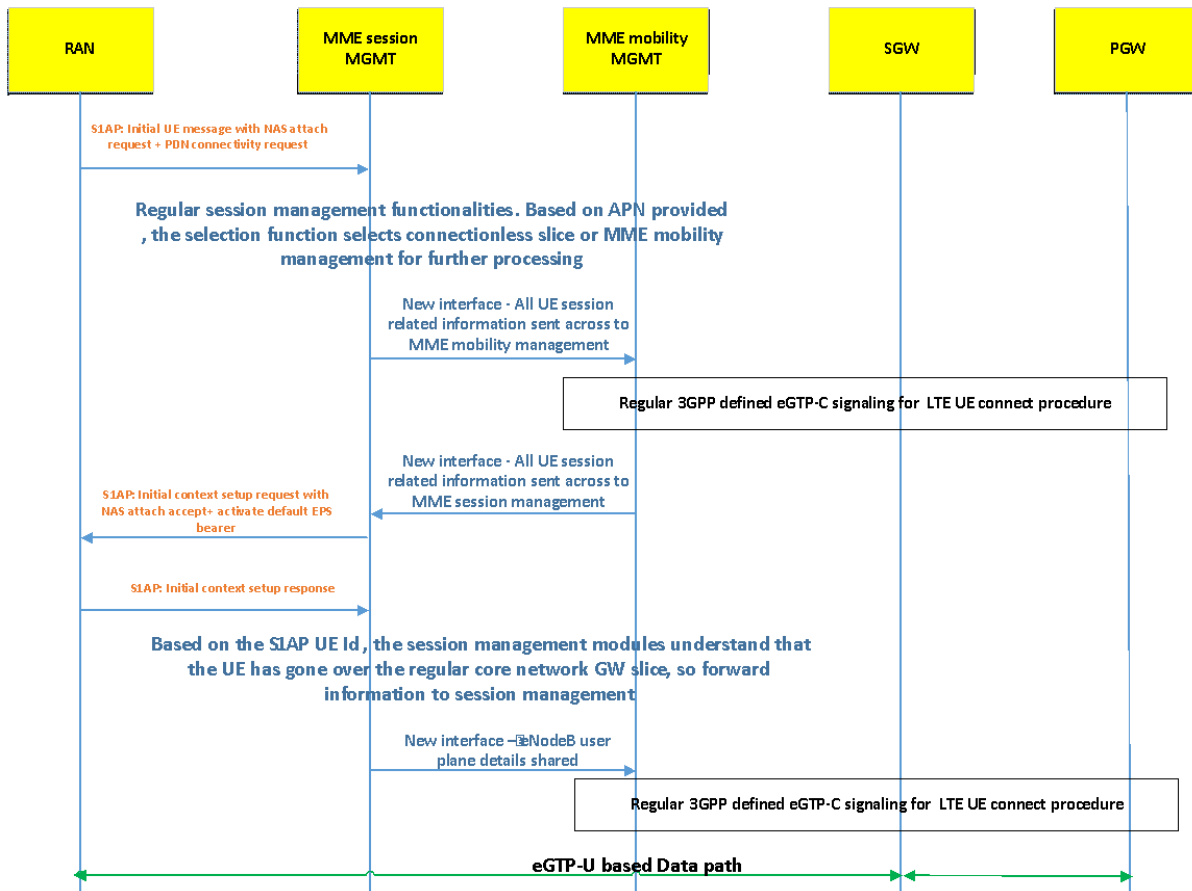


1. The standard LTE interfaces are still kept valid and unchanged. For example, S1C, S1U, S11 etc.
2. The MME is disaggregated into
 - session management entity. This also does a packet core GW selection function (based on APN)
 - mobility management entity. Interfaces with SGW and other network nodes required for mobility.

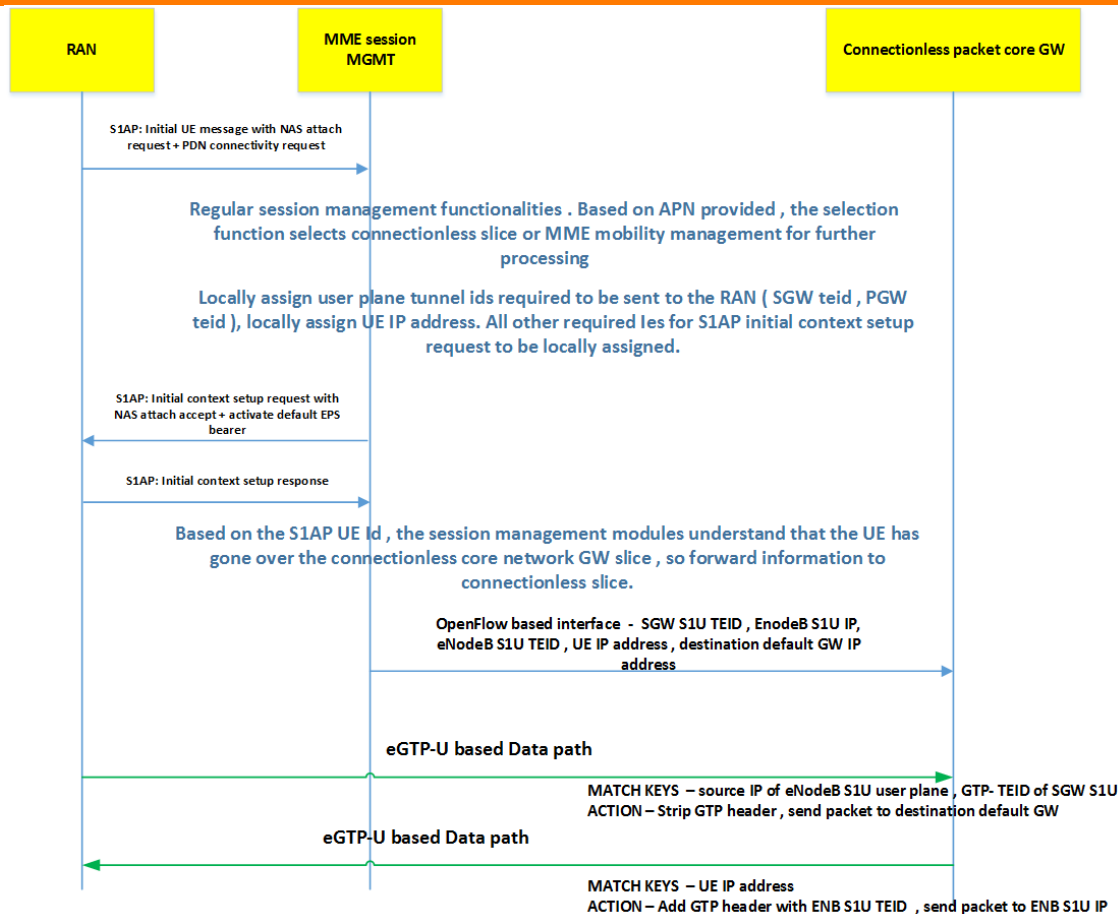
3. The figure shows the control plane and user plane signaling path for a regular UE and a static IoT device over the standard LTE architecture. As shown above –

- The regular UE traverses the standard path for control and user plane.
- The static IoT device control plane signaling does not through the legacy core network GW slice (SGW and PGW), instead it is short circuited at the MME session management. And the user plane i.e. S1U goes to a new connectionless core network user plane slice egressing out to the Gi LAN.

Call flow for LTE UE



Call flow for Static IoT device

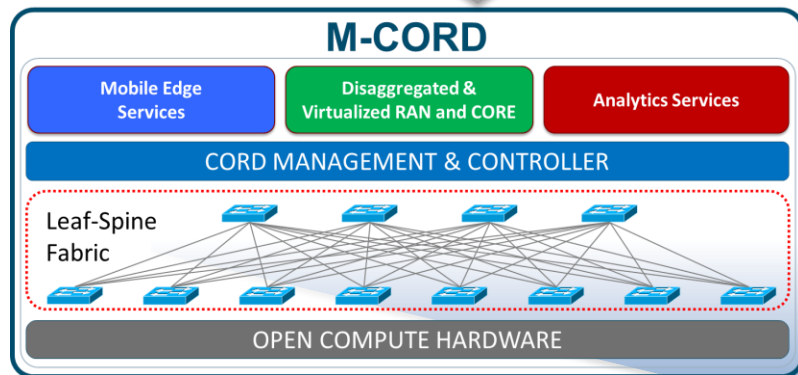




M-CORD Innovations: SDNized Scalable CORE



IoT + Non-IoT on current LTE leads to excessive signal overhead

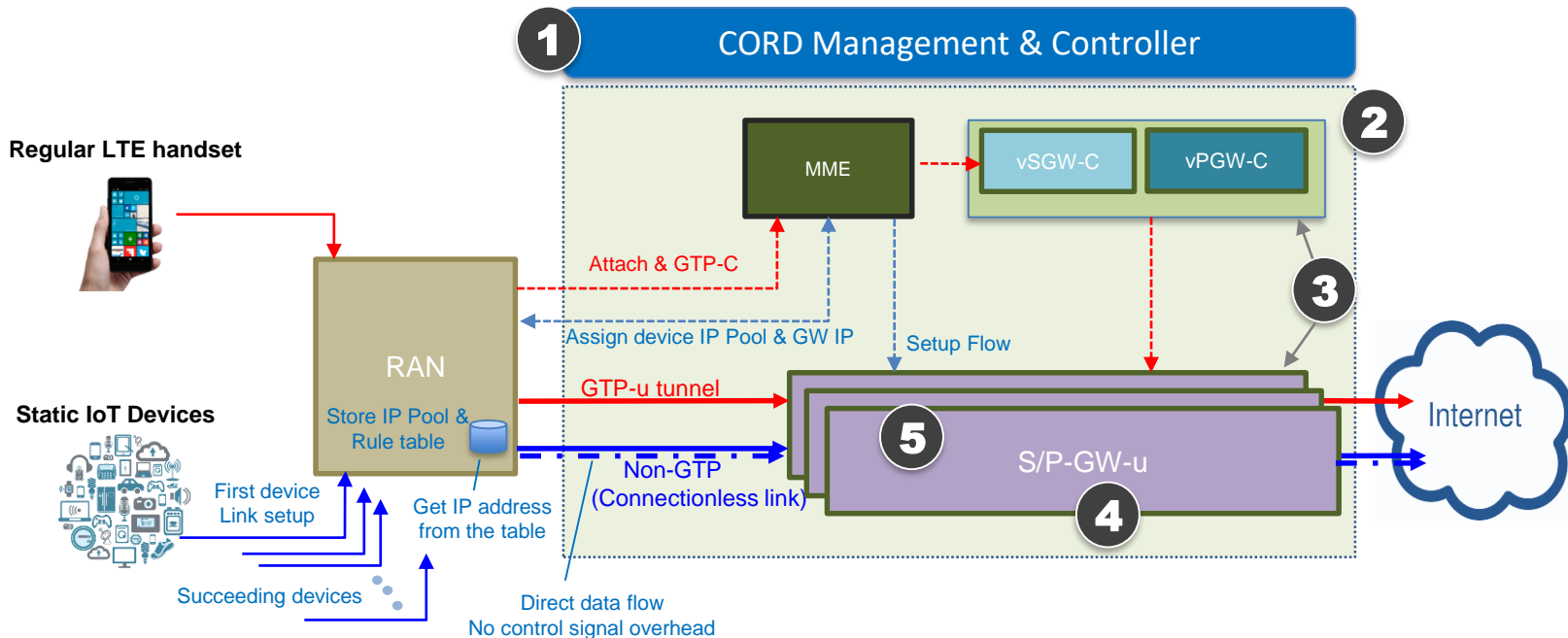


- Flow classification at RAN
- GTP & GTP-less support
- Scalable Connectionless GW

SDNized Scalable & Connectionless CORE



M-CORD Innovations: SDNized Scalable CORE



1 CORD Open Software Platform

2 Open source CORE

3 Disaggregation of control and data

4 DPDK-based scalable data plane

5 Connectionless data plane (Non-GTP)

Objectives

Problem to solve:

Traditional 3GPP tunnel/bearer based connection-oriented architecture will not scale in cost effective way in 5G with 10's billions of devices. Explore leveraging SDN and simple IP to effectively deliver **connectionless** based Wireless as a Service (WaaS) platform **across all radio** technologies and HetNet with higher degree of **flexibility and scalability**. In addition, **reducing # of states and # of copies of the states** maintain in the network is very desirable.

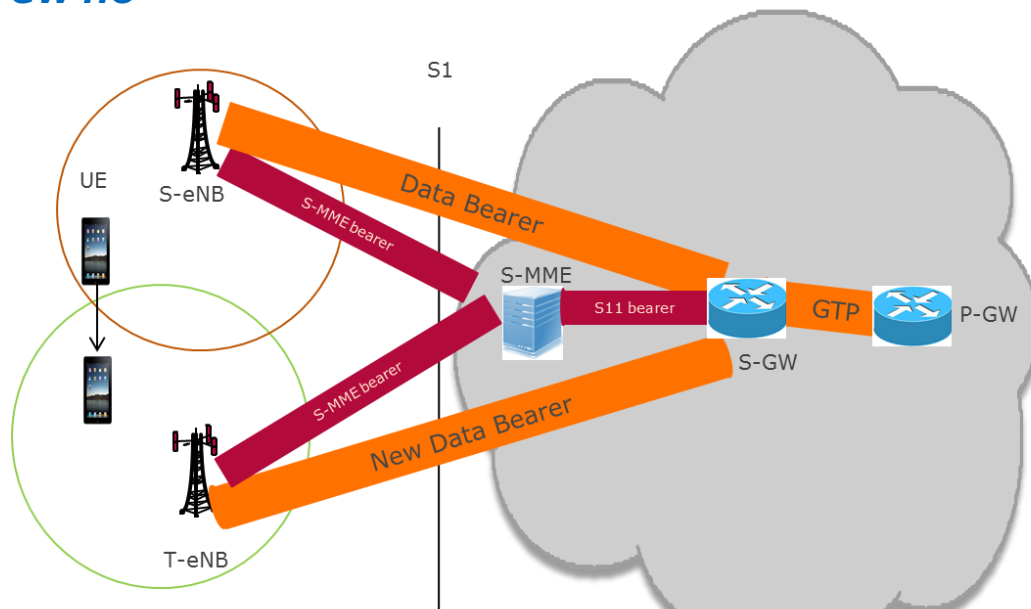
Potential Benefits:

SDN for WaaS provides flexibility, programmability, and quick TTM with

- **Simpler and scalable** wireless management by using simple IP protocol with SDN control **instead of expensive GTP** for different RATs, bigger opportunity for **plug-in** of new RAT or mobility management features, and **adaptive to future**
- **Common and open control** across all wireless technologies, e.g. LTE, Wi-Fi, any future 5G access technologies.
- **Common platform** for RAN control/management functions such as mobility management, session management, load balancing, Intelligent RAT selection, higher layer radio scheduling and coordination, QoS, etc.
- Easy adaption to different applications (e.g. M2M) and much more granular differentiated services and treatment

GTP-Based Cellular Network Example

LTE S1-based intra S-GW HO

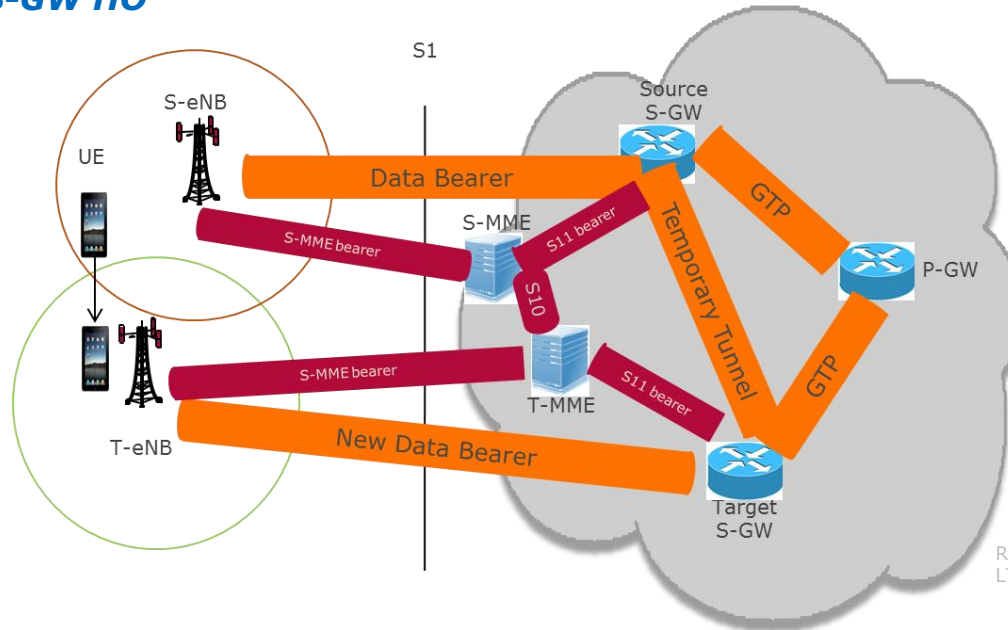


Reference:
LTE-EPC Networks And Signaling by Award Solutions

In this intra S-GW HO example, S-eNB sends a HO request message to the MME indicating the T-eNB as target cell. MME establishes a new S1-U bearer between the T-eNB and S-GW to route traffic from/to P-GW.

GTP-Based Cellular Network Example

LTE S1-based inter S-GW HO



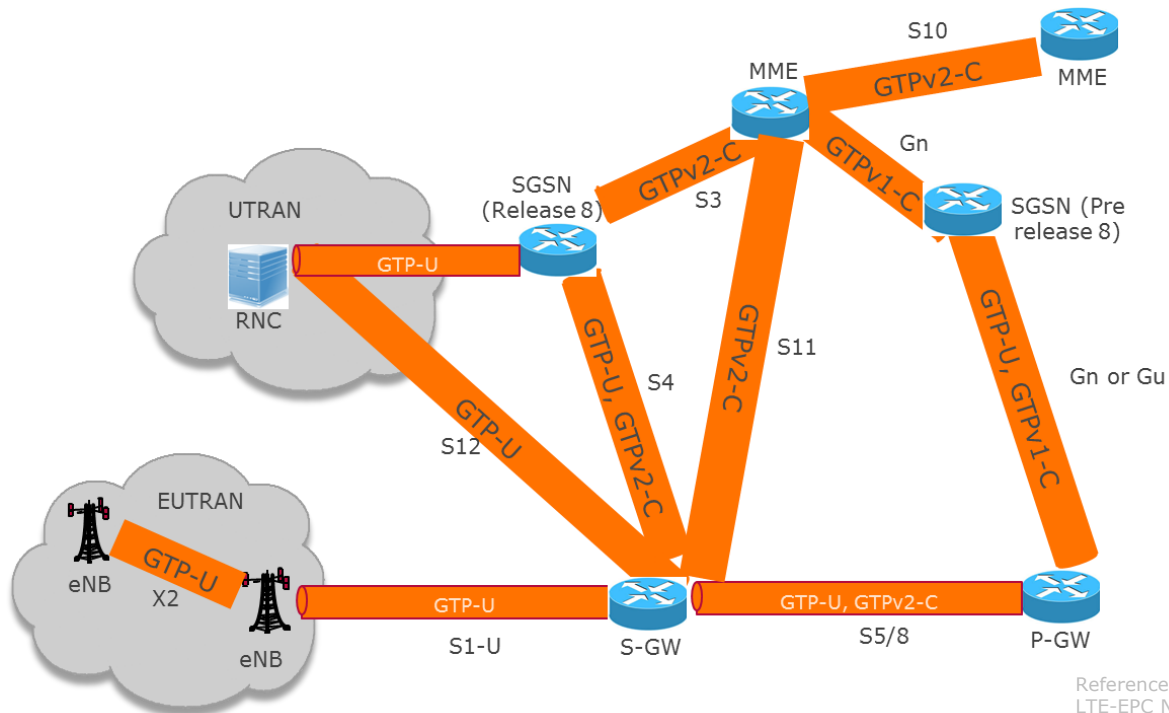
Reference:
LTE-EPC Networks And Signaling by Award Solutions

In this inter-MME example, S-eNB sends a HO request message to the S-MME indicating the T-eNB as target cell. S-MME determines the target MME (T-MME) and forwards the UE's context to the T-MME.

T-MME establishes a new S1-U bearer between the T-eNB and Target S-GW; establishes a GTP tunnel between Target S-GW and P-GW; also in order to avoid losing packets on the old EPS bearer, the Target S-GW also setup temporary tunnel between the two S-GW, so the downstream data arrived at S-eNB can be forwarded to T-eNB via Source S-GW, Target S-GW, then to T-eNB. The signaling for these GTPs and the states have to be maintained are very complex.

GTP-Based Cellular Network Example

LTE & UMTS



Note, there are three versions of GTP-C are defined by the 3GPP:

- Version 0 – for Release 97/98 of GPRS
- Version 1 – for Release 99, e.g. Gn interface between MME and SGSN, etc
- Version 2 – for LTE for control interfaces, such as S3, S4, S5, S8, S10, and S11

Mobility Use Cases



- UC1: SDN for Mobility Management using connectionless framework
 - Enables common mobility management across many wireless technologies, e.g. LTE, Wi-Fi, any future 5G access technologies
 - Uses simple IP protocol instead of special purpose tunnels/bearers, such as GTP.
 - Network based multiple simultaneous connectivity within/across radio technologies to improve user peak/average throughput
- Other potential UCs
 - RAN abstraction and small cell auto-discovery ,
 - Connectionless based Session management across Multi-RATs
 - Connectionless based QoS management,
 - Intelligent Multi-RAT selection in RAN,
 - Etc.

UC1 - SDN for Mobility Management

Table 1. E-ANR table

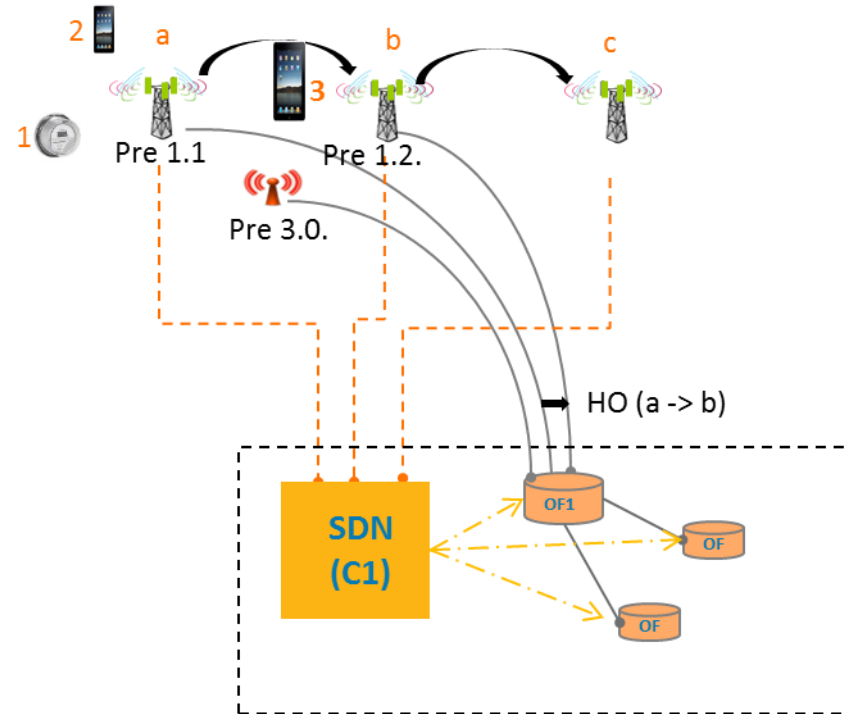
	pre	RAT	Cell-type	load
a	1.1	LTE	Ma	H
b	1.2			
c	3.0			

Table 2 UE information (before HO for UE3)

UE	Session/Client address	Act1-addr	Act2-addr	Addr-1	Addr-2	Addr-3	Mob. state
1	10.10.0.1	1.1.0.1					S
2	10.10.0.2	1.1.0.2	3.0.0.2	1.1.0.2	1.2.0.2	3.0.0.2	M
3	10.10.0.3	1.1.0.3		1.1.0.3	1.2.0.3	3.0.0.3	M

Table 3. UE information (after HO for UE3)

UE	Session/Client address	Act1-addr	Act2-addr	Addr-1	Addr-2	Addr-3	Mob. state
1	10.10.0.1	1.1.0.1					S
2	10.10.0.2	1.1.0.2	3.0.0.2	1.1.0.2	1.2.0.2	3.0.0.2	M
3	10.10.0.3	1.2.0.3		1.1.0.3	1.2.0.3	3.0.0.3	M



Incremental change to 3GPP air interface & SDN

- eNB/SDN: control ch for cell to update SDN on UE info. (similar to X2)
- [eNB/UE]: optional only need for optimization. BC cell prefix, RACH for host address
- SDN+: extend to support mobility mngt. to configure packet forwarding based on UE info

Example

- There are three UEs,
 - UE1 is a power meter,
 - UE2 is a smart phone, not moving at this moment, but may desire multi-path connectivity's for one or more sessions, and
 - UE3 is moving and is in the process of handing over from one cell to another.
- There are 6 cells (LTE/5G cells), and a WiFi AP. Cell a, b, c, and WiFi AP are controlled by SDN controller C1, c, d, e are controlled by C2, and e, f are controlled by C3.
 - Cell a, b, and AP have IP prefixes (1.1., 1.2., 3.0.) as shown in the figure.
 - UE1 and UE2 are served from or camped on to cell “a”
 - UE3 is moving away from cell “a” towards cell “b”.

How it works

1. Cells a, b, c, and the AP broadcast their prefixes to UEs. We provide the example using IPv6 address (but it could be extended to IPv4 as well).
2. UE receives the prefixes (could be more than 1) from the cells and Wi-Fi AP and appends its own host address (e.g. lower 64 bits) to form one or multiple IP addresses, depending on the number of received prefixes of cells/AP.
3. The distributed SDN controllers (e.g. C1, C2, and C3) perform mobility management functions including but not limited to the following functions:
 1. Setting up Table 1 –E-ANR (enhanced ANR table), which captures the characteristics of neighbor cells/APs
 2. Maintain UE information table, including adding/removing/updating the UE entry with UE location, mobility status, candidate IP addresses associated with current or past serving cells/APs, and the active IP address(es). In the case of multi-homing there will be multiple active IP addresses for that UE. (e.g. concurrent connectivity among Wi-Fi/cellular integration ISRP, multi-path TCP, ...)
 3. Facilitate a handover by re-directing active UE flows from a previous location to a new location for their lifetime.
 4. Dynamically configure switching/routing table on the switch/router component in order to route the user traffic to/from the proper cell(s)/AP(s). This reflects the connection setup and HO decision.

How it works (cont'd)

- **Examples of UE1, 2, 3:**

1. Lets look at UE1 – Non-mobile case

- i. Assume UE1, a power meter, camps on cell (a) and has packets to send. It starts the attach procedure to get authenticated. UE1 also appends its host address (e.g. lower 64 bits of the full IPv6 address 0.1) to the prefix of cell (a) and sends its full IP address associated with cell a “1.1.0.1” to SDN controller C1 in the attach procedure.
- ii. C1 adds an entry to the UE Information table for UE1 as shown in table 2. In this case, UE1 is not going to move. It has a simple entry with only one IP address. After UE1 finishes sending packets, it goes through detach after inactivity timer times out. C1 deletes the entry of UE1
- iii. The point of this case is to show how simple non-mobile access is performed in a lightweight, low-state approach. This speaks to scalability for simple devices.

2. Lets look at UE2 – Multipath case

- i. Assume UE2 is a smart device that's stationary. It's under the coverage of cell (a) and the Wi-Fi AP. UE2 is running a high bandwidth movie download and uses MP-TCP. Similar to UE1, UE2 has an IP address, 1.1.0.2, associated with cell (a). In addition, UE2 also has an IP address, 3.0.0.2, associated with the Wi-Fi AP. C1 learns about UE2's IP addresses through their allocation (e.g. DAD).
- ii. C1 adds an entry to the UE Information table for UE2 as shown in table 2. C1 marks both IP addresses associated with cell (a) and Wi-Fi AP active.
- iii. C1 now provides intelligence for use of the duplicate paths. It can resolve host addresses for UE2 so that inbound load is distributed, for the MP-TCP case C1 doesn't need to do very much.

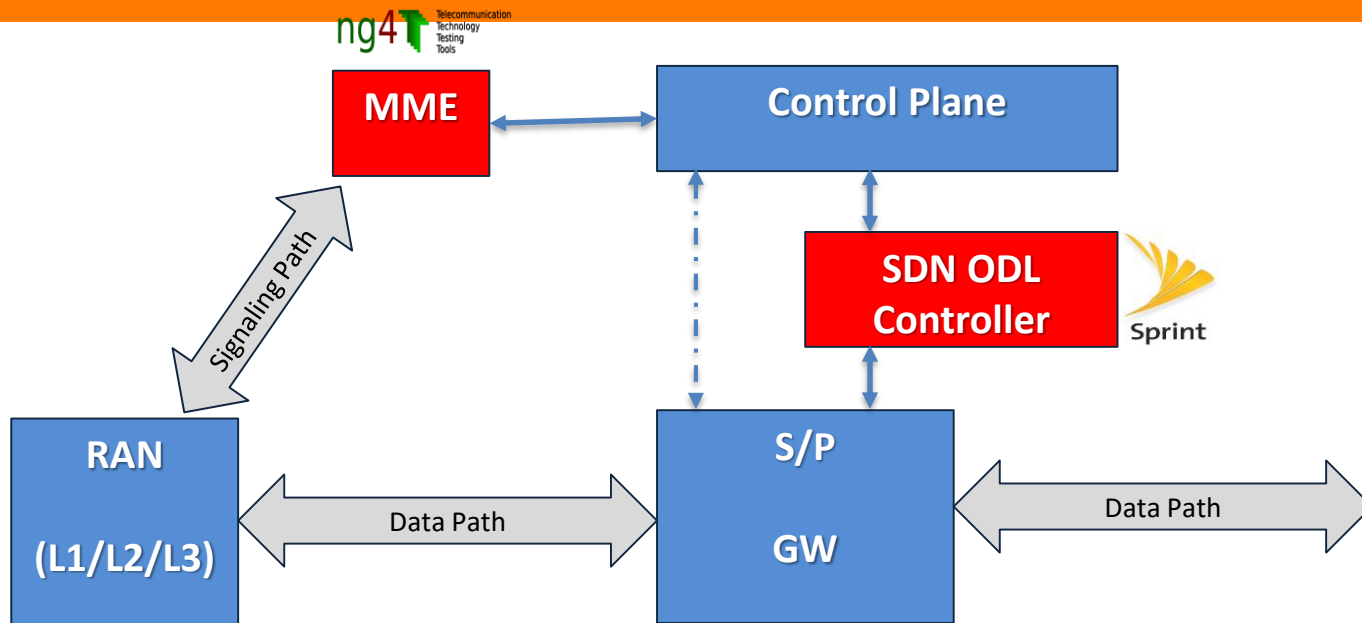
3. Lets look at UE3 – HO case

- i. UE3 is moving away from cell (a) towards cell (b), and HO occurs when HO conditions are met. UE3 has three valid IP addresses 1.1.0.3, 1.2.0.3, 3.0.0.3.
- ii. C1 updates the UE3 entry to reflect the HO from cell (a) to cell (b) as shown in table 2 and 3. Ongoing flows for cell (a) are sent toward cell (b) after HO, so a mobility protocol like ILNP or LISP-MN is not needed.

Connectionless Core

collaboration with Intel

SDN based Virtual Evolved Packet Core (vEPC)



Today Intel Labs has:

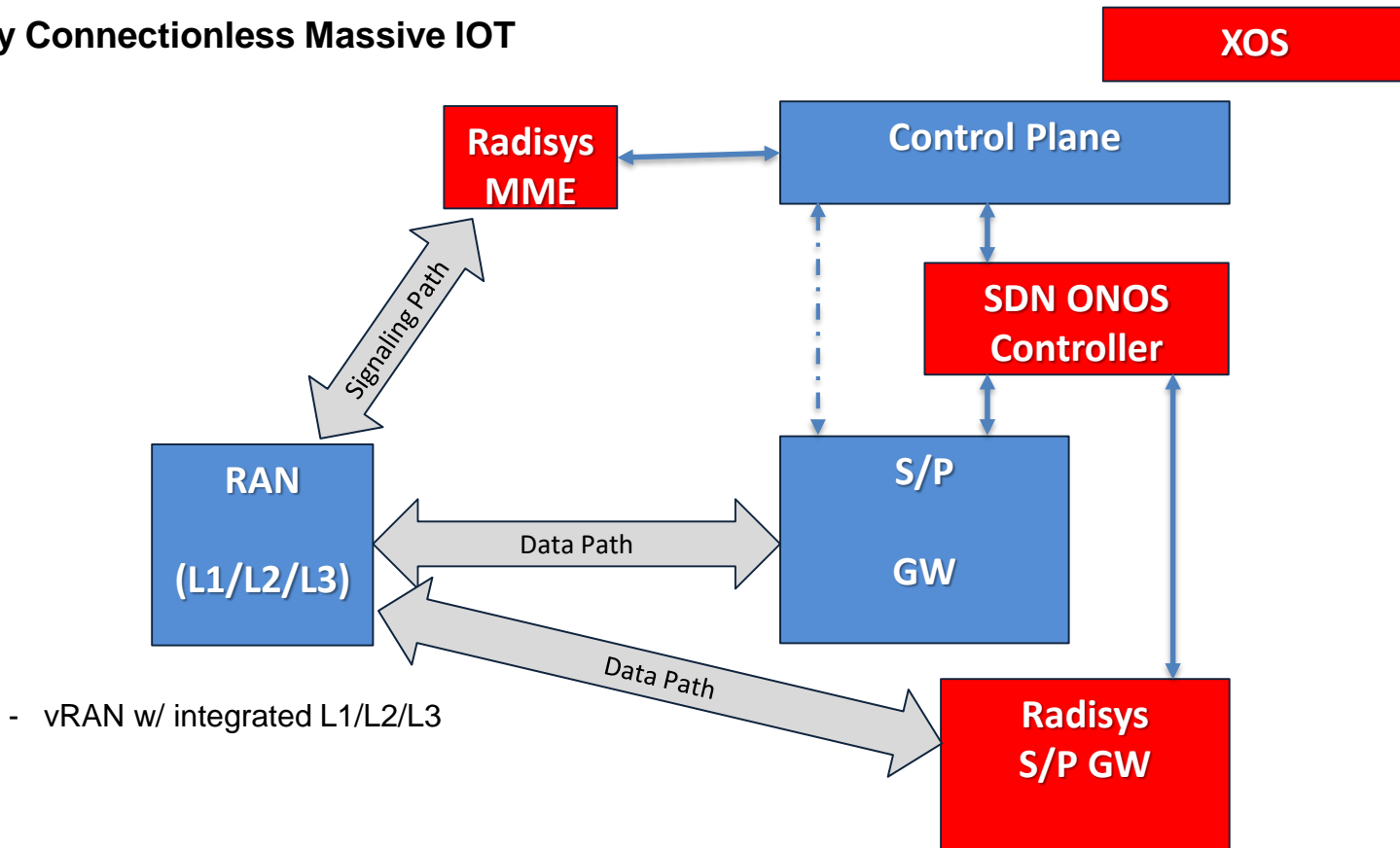
- vRAN w/ integrated L1/L2/L3
- Not disaggregated L2/L3 yet, that's in biz unit
- Working w/ Intel Legal and NPG to open source

Today Intel Labs has:

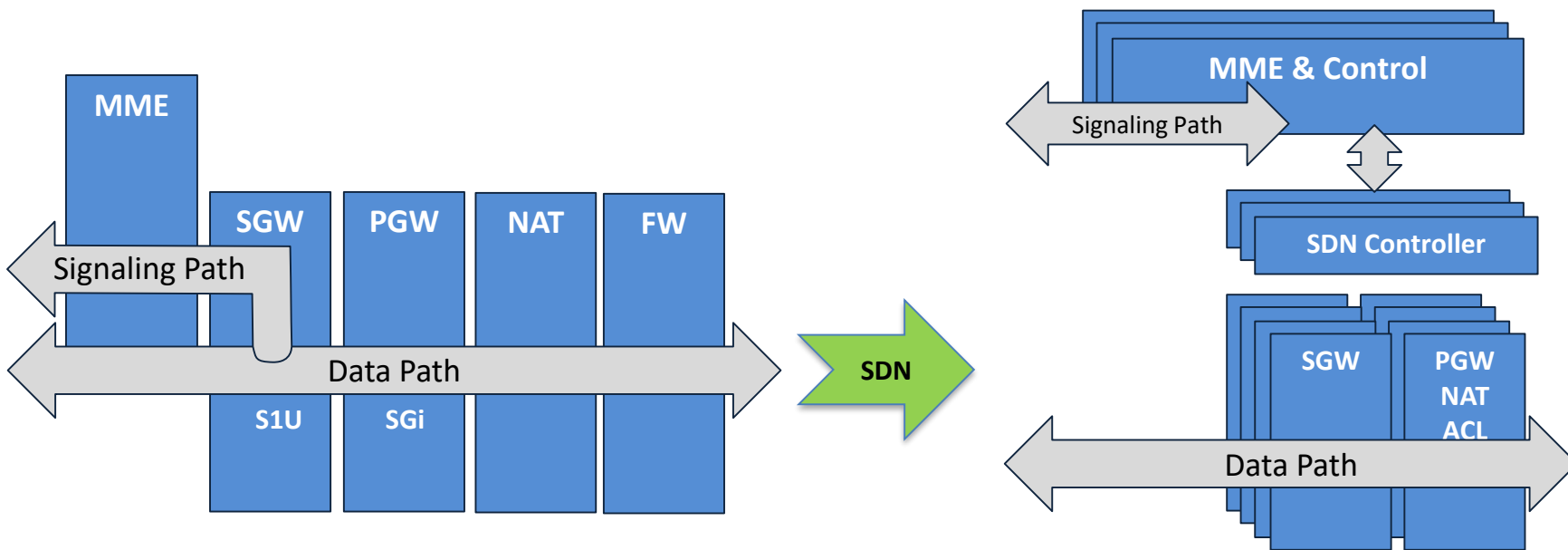
- S/P GW, high performance – Reference implementation, we're not selling any
- Disaggregated CP/DP
- Using ODL controller w/ ZeroMQ SB interfaces
 - Tried OF 1.3.1 but lacking properties for wireless
- Runs as bare-metal/VM, needs VTd/SRIOV for performance when in VM
- Will be open sourced 12/16 or 01/17 at latest – Community TBD

M-CORD for MWC

Stationary Connectionless Massive IOT



Vision: SDN based Scalable Evolved Packet Core



Identified system's bottleneck

IEEE LANMAN '15

No independent control or data scaling

Independent functionality

- SDN based architecture
- Independent control or data scaling
- Collapsed functionalities



M-CORD Innovations: End to End Slicing



5G

REQUIREMENTS

- Network slicing
- Differentiated traffic treatment for diverse devices, users, & services
- Mobile Virtual Network Operator (MVNO)

M-CORD

Mobile Edge
Services

Disaggregated &
Virtualized RAN and CORE

Analytics Services

CORD MANAGEMENT & CONTROLLER

Leaf-Spine
Fabric

OPEN COMPUTE HARDWARE

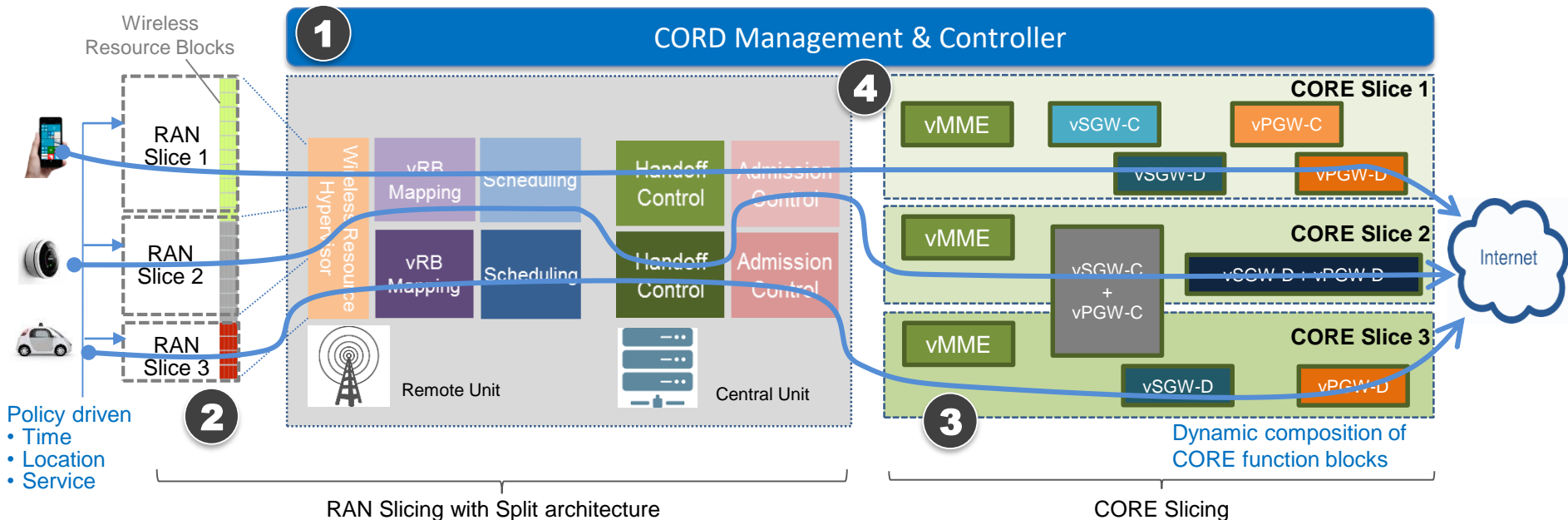


- RAN & CORE slicing
- E2E Orchestration & Network Slicing as a service

Dynamic & Programmable End to End Slicing



M-CORD Innovations: End to End Slicing



1 CORD Open Software Platform

2 RAN Slicing

3 CORE Slicing

4 End to End Slicing Orchestration

Network Slicing

■ PROBLEM STATEMENT (by NGMN)

- 5G use cases 는 다양한 요구사항을 필요로 함
- 현재 다양한 서비스를 수용하기에는 너무 monolithic한 구조로 Flexible 하지 않고 Scalability도 부족
- 다양한 비즈니스 는 각각의 특별한 성능, 확장성, 가용성의 요구 조건이 있음



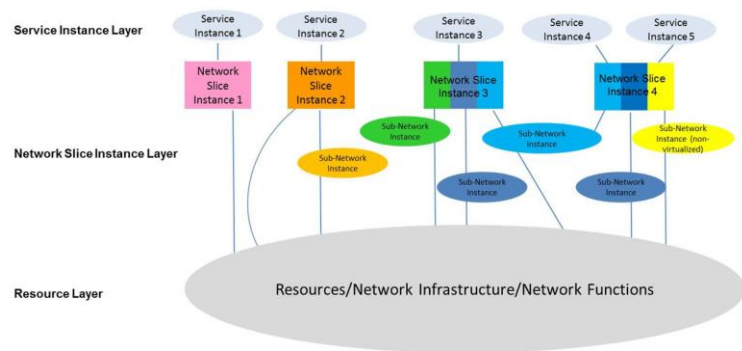
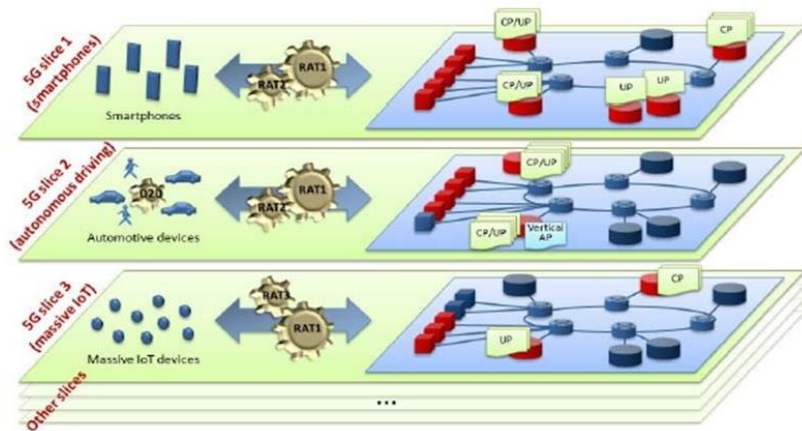
■ General definition

- ‘Network slicing aims to provide dedicated logical networks with customer specific functionality and associated network control without losing the economies of scale of common infrastructure, allowing for operational isolation.’

Network Slicing in NGMN

■ NGMN definition

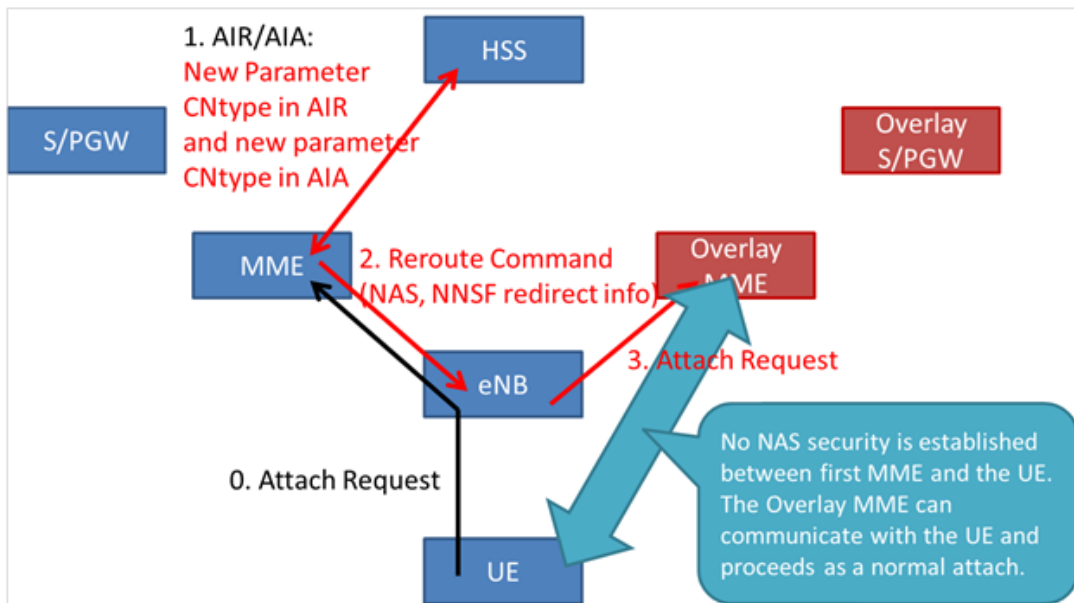
- “5G slice”, supports the communication service of a particular connection type with a specific way of handling the C- and U-plane for this service
- To this end, a 5G slice is **composed of a collection of 5G network functions and specific RAT settings that are combined together for the specific use case or business model.**
- Network slicing concept consists of 3 layers:
 - 1) **Service Instance Layer,**
 - Can be provided by operator or by 3rd parties
 - 2) **Network Slice Instance Layer**
 - “Network Slice Instance: a set of network functions, and resources to run these network functions, forming a complete instantiated logical network to meet certain network characteristics required by the Service Instance(s)”
 - 3) **Resource layer.**



Network Slicing in 3GPP

■ DECOR

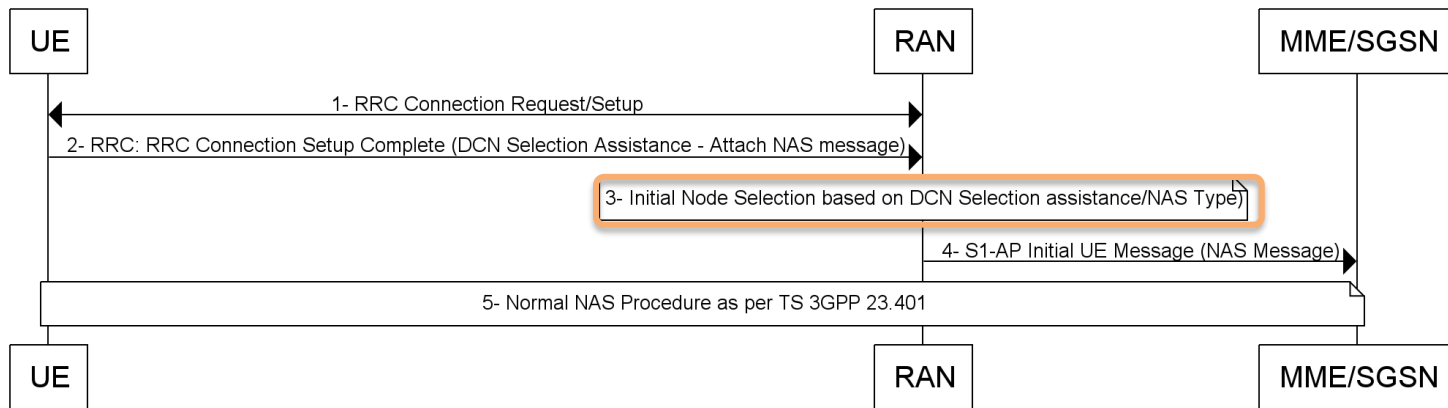
- 3GPP Rel.13 (TR 23.707 http://www.3gpp.org/ftp/specs/archive/23_series/23.707/23707-d00.zip)
- Dedicated Core Network
- MME to redirect traffic to another mobile core.
- 단말 변경 불필요
- HSS, eNB, MME 변경
- 단점: redirection 불가피



Network Slicing in 3GPP

■ eDECOR

- 3GPP Rel.14 (http://www.3gpp.org/ftp/tsg_sa/WG2_Arch/TS GS2_110_Dubrovnik/Docs/S2-152661.zip)
- DCN 선택 시 UE 에 추가되는 보조 정보 이용 (즉, UE 변경 필요)
→ redirection에 따른 signaling 감소 및 isolation 향상



Network Slicing in 3GPP

■ NG Architecture (TR 23.799 Rel .14 http://www.3gpp.org/ftp/Specs/archive/23_series/23.799/)

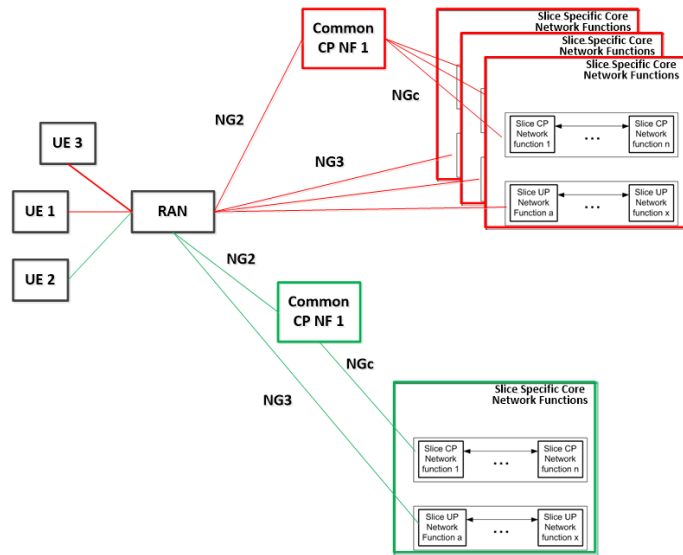
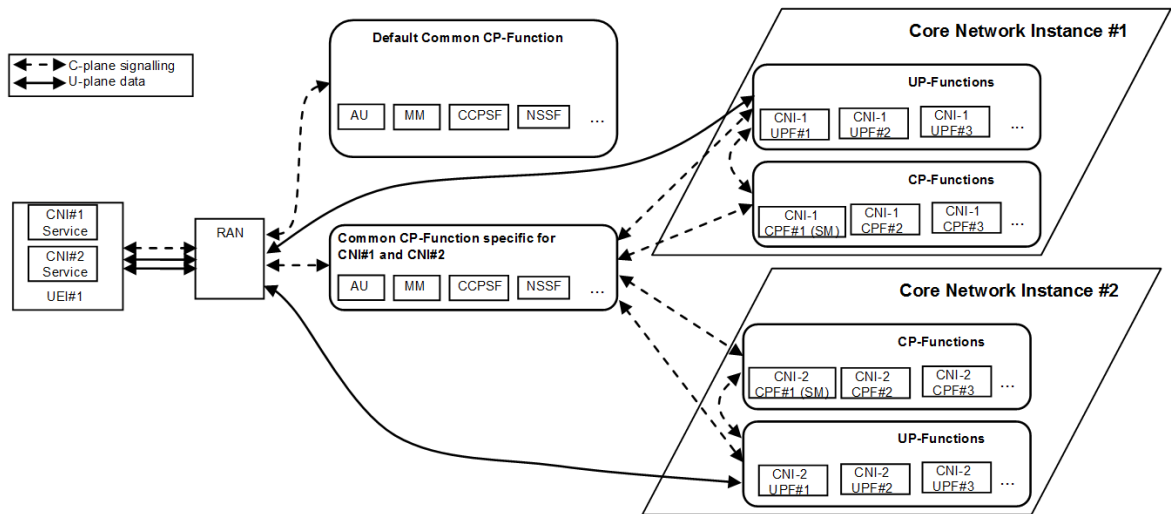
[Solution#1]

Core Network를 slice에 공통인 CCPSF (Common Control Plane Selection Function)과 SCNF (Slice Specific Core Network Function)으로 조합 구성

→ Selection은 UE에 설정되는 MDD (Multi Dimensional Descriptor) 사용

[Solution#2]

- Network Slice Selection Function (NSSF)
- Common C-Plane Selection Function (CCPSF)



Network Slicing, 주요 특징 및 implications

	다른 서비스 트래픽을 다르게 취급 (Capability to treat flows of different services differently)	해당 서비스에 필요한 기능만 제공 (Provide only necessary traffic treatment for the use case)
기술적 implication 및 TCO, 운용 영향	<ul style="list-style-type: none"> • Slice 별 전용 resource/function을 할당하거나 → TCO ▲요인, 운용복잡성 ▲요인 • 공통 resource/function을 share하거나 → TCO ▼요인, 운용복잡성 ▲요인 • 공통 resource / 전용 resource 조합 (예: HSS, SGW 공유, MME, PGW 전용) → TCO ▲▼요인, 운용복잡성 ▲요인 	<ul style="list-style-type: none"> • 각 슬라이스를 필요한 최소한의 기능만으로 구성 • 현 System 단위를 functional disaggregation 으로 세 분화 → TCO ▼요인, 운용복잡성 ▲▼요인
비즈니스 implication	<ul style="list-style-type: none"> • Slice간 서비스 영향 제거해 안정적인 품질, 높은 security 제공 가능 • 고객 요구사항에 따라 Capacity, Redundancy 등 Customize 	<ul style="list-style-type: none"> • 고객 요구사항에 따라 Network Function Customize & 최적화 가능
	<ul style="list-style-type: none"> • slice 운용 자율권도 부여 가능(MVNO, Enterprise) • Media, Massive IoT, Mission-critical IoT 등 use case 특화망 비즈니스 가능 	

- ☞ Network slicing은 복합적 요인 즉, slicing 구성방식, 신규 기술 도입 비용, 기술 발전에 따른 H/W 및 S/W 비용 구조 변화 등에 따라 TCO 증가/감소 요인 공존. 관련 표준이 3GPP에서 논의 중이라 아직 본격적으로 전체망 Network slicing 도입 사례 없음
- ☞ 다양한 서비스, 3rd party 참여 통한 innovation, New Business enabling 차원에서 필요성에 consensus가 모아지고 있음



Safety service



Requires more intelligence
with diverse destination & format



audio



video



location



map

M-CORD

Mobile Edge
Services

Disaggregated &
Virtualized RAN and CORE

Analytics Services

CORD MANAGEMENT & CONTROLLER

Leaf-Spine
Fabric



OPEN COMPUTE HARDWARE



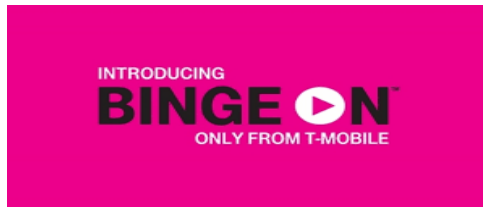
- Traffic classification
- Network cookie
- User-driven application

Premium Public Safety Service

HOW TO MAKE ZERO-RATING BETTER FOR USERS

- Yiannis Yiakoumis, Sachin Katti, Nick McKeown
- Stanford University

Differentiated Pricing + QoS



5G Network slicing, fast lanes, background lanes...

Hard to deploy + Controversial

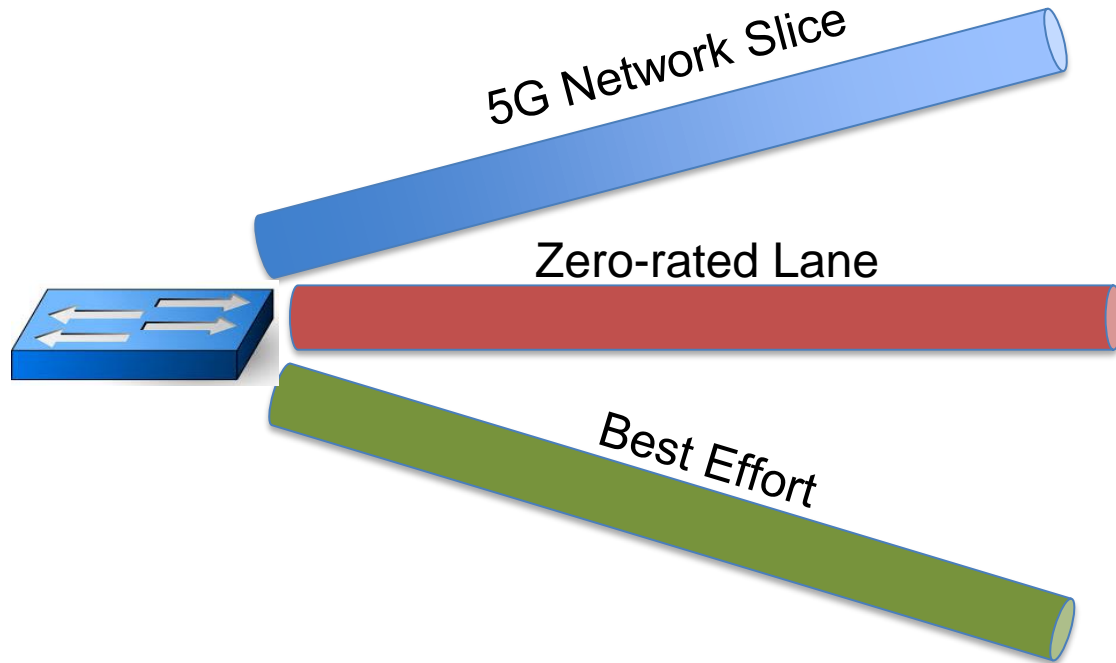
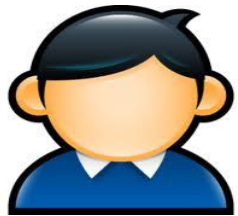
1. What traffic gets what treatment?

- 이미 special treatment를 해주는 서비스가 있음
 - facebook zero
 - T-mobile Music Freedom

2. How to align with net neutrality policy?

- 결국은 고객의 피해로 돌아 갈 것이라는 concern. ← ISP와 CP가 어떤 application에 better treatment를 할 것인지 결정하게 되어 innovative new application에 대한 진입 장벽이 될 수 있어서
- 그래서 Net neutrality는 “Don’t do anything” 주의 (treat all traffic the same)

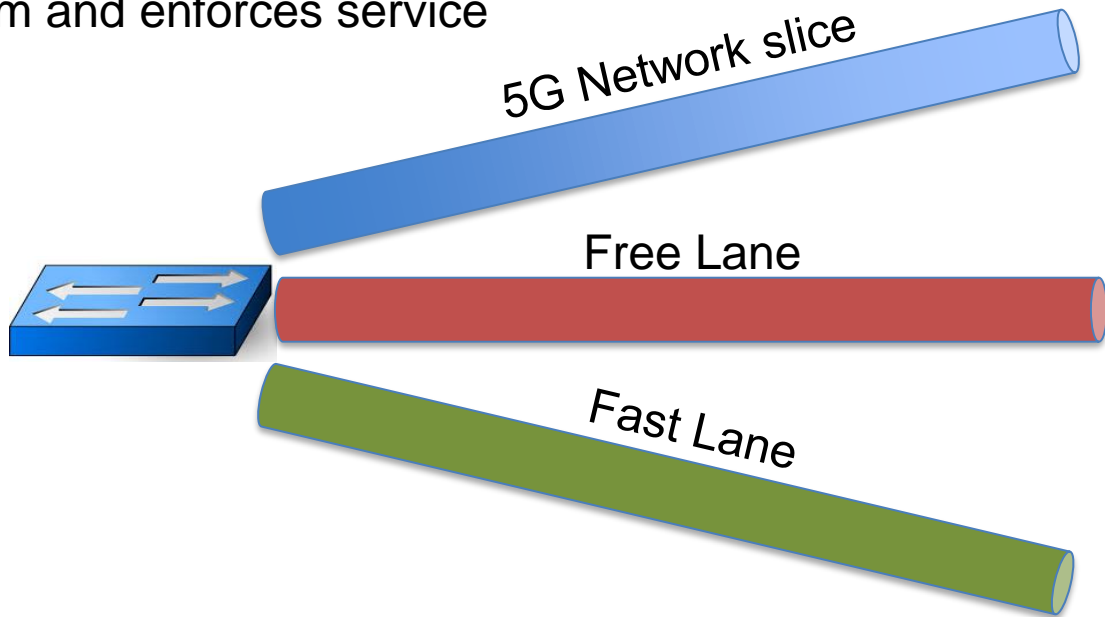
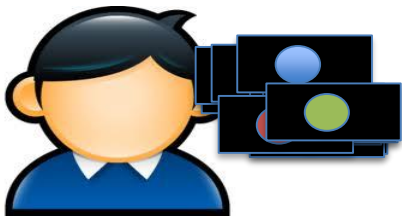
Step 1 : Easily map any traffic to any service



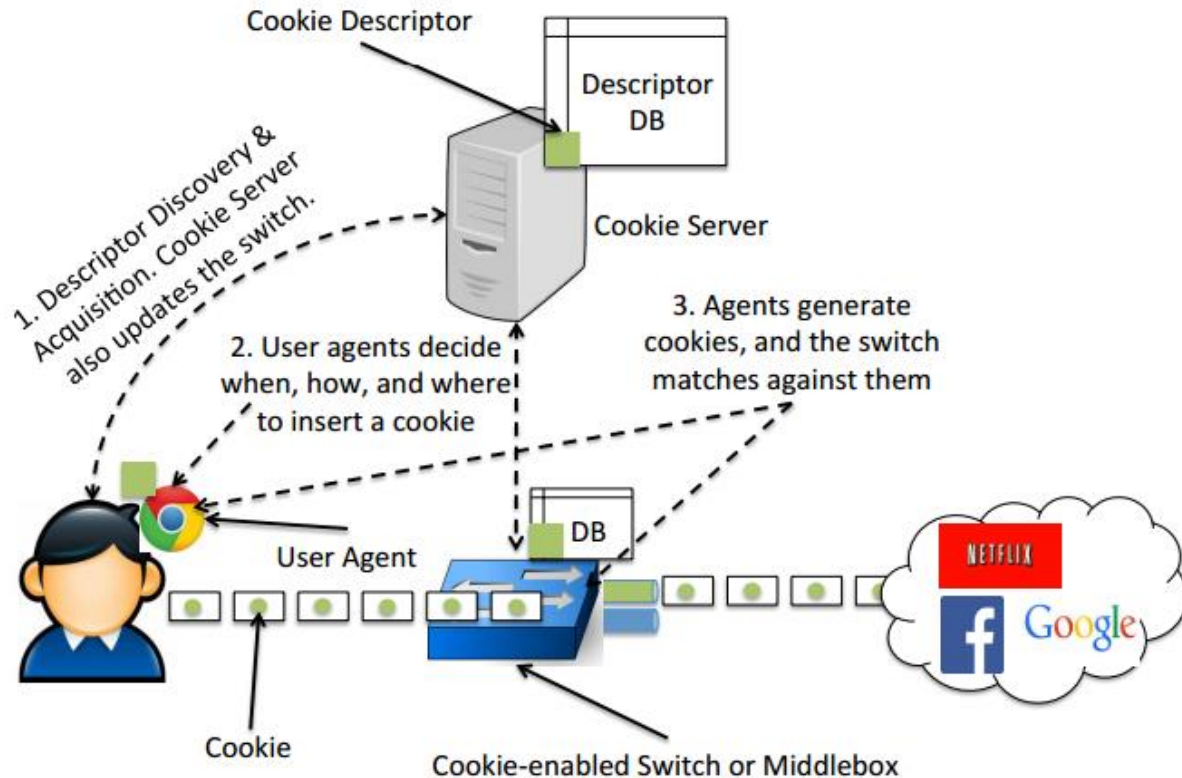
Network Cookies: a mapping abstraction

Network Cookie : A small piece of data users append to their traffic

1. Get **cookie** for each service
2. User appends cookies to the desired traffic
3. Network matches against them and enforces service

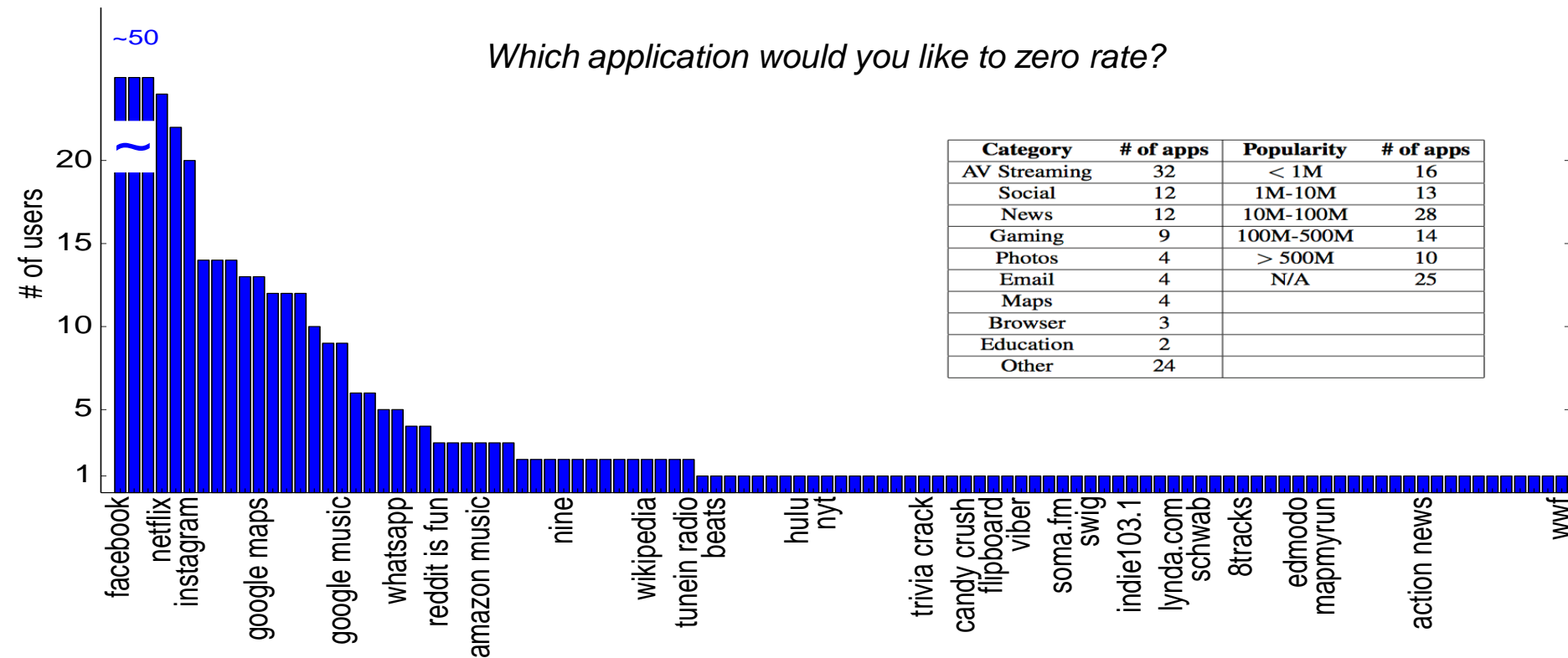


Network Cookies

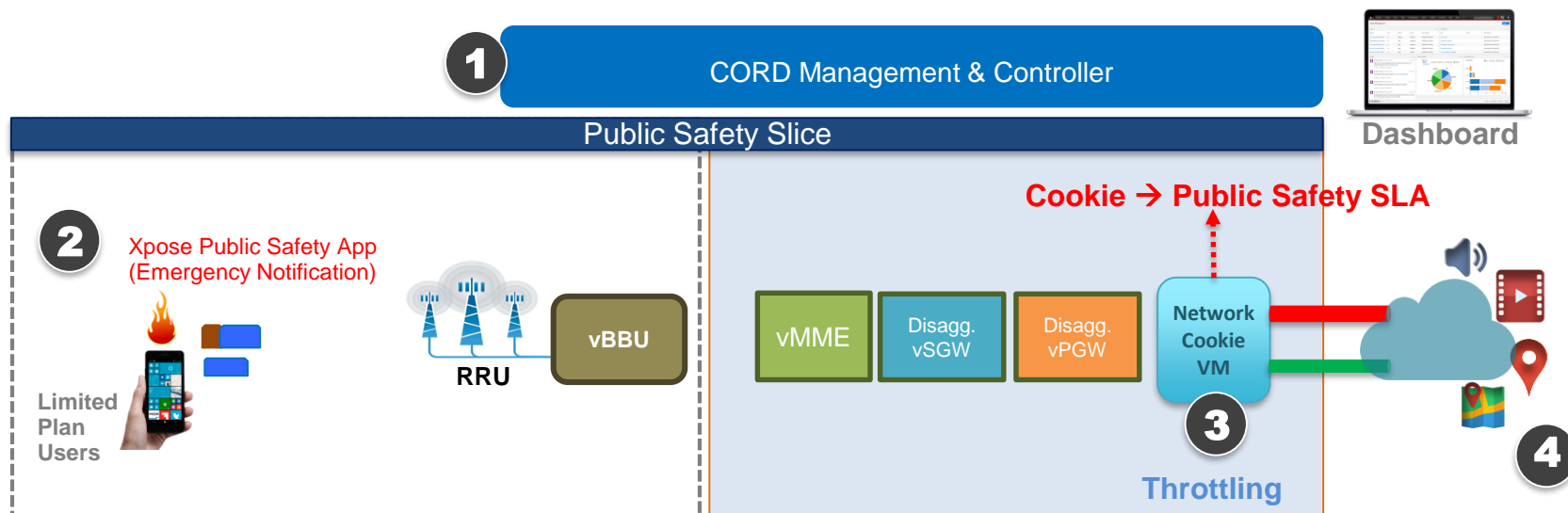


Step 2: Give users control

Which application would you like to zero rate?



Category	# of apps	Popularity	# of apps
AV Streaming	32	< 1M	16
Social	12	1M-10M	13
News	12	10M-100M	28
Gaming	9	100M-500M	14
Photos	4	> 500M	10
Email	4	N/A	25
Maps	4		
Browser	3		
Education	2		
Other	24		



1 CORD Open Software Platform

2 Xpose Public Safety App

3 Network Cookies API for traffic differentiation

4 Support for multiple Traffic Types / Apps

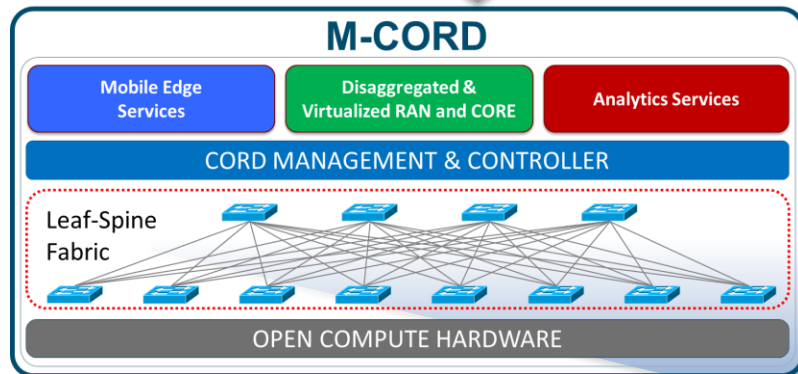


M-CORD SERVICES: Adaptive Analytics Service



Service assurance solution requires

- Model driven approach
- Dynamic analytics



- Adaptive monitoring
- Anomaly detection
- Active testing
- Closed loop automation

Model Driven Assurance and Testing as a Service



M-CORD SERVICES: Adaptive Analytics Service

